Best practice guide to work in confined spaces. Blades

Produced by:

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Index

1. Introduction

A confined space is any space with difficult access and exit and restricted natural ventilation. In addition to many other physical and mechanical risks, toxic or flammable pollutants may accumulate in such spaces and they may be deprived of oxygen. These spaces are not suitable for the worker's continued presence (ref.1).

Working in confined spaces entails serious and even mortal risks that are often overlooked; as a result, measures, which could have avoided an incident, are often ignored.

A wind turbine is a large machine with a number of spaces with different access requirements; these spaces may be open or closed, and they may be classified as confined or not.

However, our experience with wind turbines leads us to define one particular space as being confined:

- The interior of the wind turbine blade: this area remains a confined space irrespective of whether it is in the production plant, being installed or already assembled as part of the wind turbine.

Source: LM Wind Power

There are two further spaces that may sometimes be defined as confined spaces:

- The base of the wind turbine, when the high-voltage generator is housed on the entrance platform.
- The rotor, when there is not sufficient ventilation due to its sealing and/or when it houses battery cabinets.

In general, all other parts of the wind turbine can be regarded as having difficult access, but they are not classified as confined spaces as they generally have more than sufficient ventilation.

2. Purpose

In this document, we seek to set out the recommendations to be followed by both the company and the workers when accessing the interior of a blade, whatever its location, whether it is located in the production plant, being installed or already assembled as part of the wind turbine.

Source: LM Wind Power

3. Methodology

First, we examine operating risks, before moving on to examine interactions between the three classic aspects of occupational health and safety:

- The environment (environmental requirements).
- The machine (geometric requirements).
- The person (worker requirements).

And the main element that links these, the physical load.

Finally, we will examine protective and work equipment, signalling, organisation and supervision and emergency management.

In preparing this document, we have referred to a number of domestic and international sources in order to provide the reader with decision-making criteria that will help them manage work inside wind turbine blades.

Source: LM Wind Power

4. Risks accessing the blade

In blades in any position (on the ground or installed):

- Asphyxia.
- Poisoning.
- Crushing.
- Falling over.
- Physical environment:
    - Heat and cold.
    - Noise.
        - o Vibration.
        - o Light.
- Psychosocial.

And in the case of repairs:

- Fire or explosion.
- Repair work uses resins, catalysts and fibres .

And in the case of installed blades:

- Falling from height.

Source: Gamesa

5.Environmental requirements

5.1 Working at low temperatures

The main problem when working in very cold spaces is freezing of people exposed to wind.

On the next page, we present a proposed plan for working at low temperatures that can be applied to working in the blade.

Obviously, workers should be wearing personal protective clothing when working at such temperatures.

It is important to always consider the option of negligible wind when working in the field and wind force when working inside the blades, where the worker has to go outside in order to enter or leave the rotor. In such cases, we should consider external wind speed as a determining factor in establishing rescue times, as if a person suffers an accident, they may freeze during whilst being rescued.

<table>
<caption>Table 1
Working and break times for external workers, based on 4-hour shifts.</caption>
<tr><th colspan="2">Air temperature – clear sky</th><th colspan="2">Negligible wind</th><th colspan="2">Wind 8 km/h</th><th colspan="2">Wind 16 km/h</th><th colspan="2">Wind 24 km /h</th><th colspan="2">Wind 32 km/h</th></tr>
<tr><td>°C (approx)</td><td>°F (approx)</td><td>Max. work period</td><td>Number of breaks</td><td>Max. work period</td><td>Number of breaks</td><td>Max. work perio d</td><td>Number of breaks</td><td>Max. work perio d</td><td>Number of breaks</td><td>Max. work period</td><td>Number of breaks</td></tr>
<tr><td>-26° to -28°</td><td>-15° to -19°</td><td colspan="2">(Normal breaks) 1</td><td colspan="2">(Normal breaks) 1</td><td>75 min.</td><td>2</td><td>55 min.</td><td>3</td><td>40 min.</td><td>4</td></tr>
<tr><td>-29° to -31°</td><td>-20° to -24°</td><td colspan="2">(Normal breaks) 1</td><td>75 min.</td><td>2</td><td>55 min.</td><td>3</td><td>40 min.</td><td>4</td><td>30 min.</td><td>5</td></tr>
<tr><td>-32° to -34°</td><td>-25° to -29°</td><td>75 min.</td><td>2</td><td>55 min.</td><td>3</td><td>40 min.</td><td>4</td><td>30 min.</td><td>5</td><td colspan="2" rowspan="5">Work other than emergency work must be halted immediately</td></tr>
<tr><td>-35° to -37°</td><td>-30° to -34°</td><td>55 min.</td><td>3</td><td>40 min.</td><td>4</td><td>30 min.</td><td>5</td><td colspan="2" rowspan="4">Work other than emergency work must be halted immediately</td></tr>
<tr><td>-38° to -39°</td><td>-35° to -39°</td><td>40 min.</td><td>4</td><td>30 min.</td><td>5</td><td colspan="2" rowspan="3">Work other than emergency work must be halted immediately</td></tr>
<tr><td>-40° to -42°</td><td>-40° to -44°</td><td>30 min.</td><td>5</td><td colspan="2" rowspan="2">Work other than emergency work must be halted immediately</td></tr>
<tr><td>-43° and below</td><td>-45° and below</td><td colspan="2">Work other than emergency work must be halted immediately</td></tr>
</table>

*2008 TLV (Threshold Limit Values) for chemical and physical agents and BEIs (Biological Exposure Index). Cincinnati. American Conference of Government Industrial Hygienists (ACGIH) 2008, page 213

The ACGIH has adopted the guidelines prepared by the Saskatchewan (Canada) Labour Department for working outdoors in low temperatures. These guidelines recommend protective clothing and limits on exposure time (Table 1). The recommended exposure times are based on wind factors, a scale based on air temperature and wind speed. The work-break periods apply to any four-hour period of moderate to intense activity. The rest periods for "warming up" are 10 minutes in a warm place. The plan assumes that "normal breaks" are taken every two hours. At the end of a 4-hour work period, it recommends a break (for example, for lunch) in a warm place. Further information is available in the ACGIH publications "2008 TLV and BEI" (or more recent versions) and "TLV and BEI documentation" on the Saskatchewan Labour Department website "Cold conditions guidelines for outside workers" (ref 2).

Source: Vestas

5.2 Working at high temperatures

The main risk when working at high temperatures is increased internal temperature of the human body. In certain conditions, the body cannot rid itself of heat produced internally when working, resulting in a momentary "fever". This fever can result in temporary loss of concentration and generalised weakness for the person involved, increasing the risk of occupational accidents. If such a fever persists over an extended period, this may result in irreparable damage to the body.

Source: Vestas

Our problem is that it is impossible to forecast the environmental conditions in the interior of a blade. In general, the blade heats up due to the action of the Sun, reaching much higher temperatures than the outside air. Likewise, humidity conditions inside a blade can be very changeable: during the night, water may condense internally, and in the early morning, the humidity level may be well in excess of outside conditions due to rapid evaporation of the condensates.

The use of external negative pressure ventilation systems is therefore recommended to balance the internal temperature and humidity of the blade with external conditions.

There are a number of ways to establish a plan for the work/rest periods and the quantities of liquids to be consumed to balance the loss of bodily fluid: WGBT is the most common method.

Annex 1 explains the basis of the WGBT method, setting out acclimatisation policies for working in very hot environments.

6. Geometric requirements

There are a number of geometric requirements for accessing the blade.

6.1 Position of the blade

The blade should be horizontal when being worked in, as this reduces the risk of falling over and falling from height.

In the field, the blade must be securely placed on a firm base ensuring it is completely immobile, even in the event of internal forces or when it is subject to wind. The stability of the ground on which it is placed must also be checked prior to accessing the blade.

Source: LM Wind Power

However, there may sometimes be requirements to access blades that are already installed and which are not horizontal:

- In the event that the slope of the blade pushes bodies towards the rotor, identical security measures must be used to when working at height.
- In the event that the slope of the blade pushes bodies towards the tip, identical security measures must be used to when working on a rope. The blade should not be accessed when it is vertical; if this occurs, the utmost precautions must be taken, as there is a risk of the worker being trapped in the blade, in the event of an accident.

6.2 Minimum dimensions

There are two important dimensions for work within the blade:

- The scale of the work; this is what enables the worker to carry out some tasks inside the blade. The whole of the blade is not accessible, as it is very narrow at the tip. Some blades, particularly those on less powerful turbines, are not accessible at all.

- The size of the manhole giving access to the interior of the blade.

6.2.1 Working dimensions

Working within the blade requires the dimensions calculated in the EN 547 standard as a minimum:

- The average thickness of the human body for a horizontal opening in an out-stretched position (95 percentile) = 342 mm.
- Dimension of elbow width = 545 mm.

To these dimensions, we must add the supplements stipulated in the standard:

- Use of personal protective equipment = 100 mm.
- Work clothing = 20 mm.
- Free space for arm movements = 20 mm.

Therefore, the minimum size for a worker using work clothing and personal protective equipment and needing minimum arm movement would be 482 x 685.

Source: LM Wind Power

In the absence of these dimensions, we recommend that work should be performed on the ground, in order to avoid the body being trapped in the blade, from where rescue would be extremely difficult.

6.2.2 Dimensions of the manhole

The EN 547 standard stipulates the following dimensions for the access manhole:

- 342x545 mm. for oval openings.
- 50mm are added for free space of access.

The resulting minimum dimensions are therefore:

- 392 x 595 mm for oval openings.

These dimensions coincide with the established in EN50308 standard (standard not harmonized) 400 x 600 mm.

For circular openings it is accepted until 500 mm in diameter as minimum, but it has to take into account that the access will be very difficult. In that case, it is recommended a minimum diameter of 550 mm.

7. Worker requirements

7.1 Occupational health monitoring

Occupational health monitoring protocols for working at height and in confined spaces, focus on:

- Behaviour: claustrophobia, stress.
- Cardiac conditions, epilepsy, diabetes.
- For installed blades:
  - o Vertigo when working at height.
  - o Extreme physical exertion.

And for blade inspectors and repair workers:

- Checking of resins, fibreglass and catalysts (very similar to those for workers who manufacture the carcasses).

Source: LM Wind Power

7.2 Training

General:

- Working in confined spaces: work permits.
- Emergencies and rescues from confined spaces.
- Ergonomics and stress positions: physical loads.
- Use and handling of tools and machinery in confined spaces.
- Category 3 personal protective equipment: filtering equipment and self-contained and semi-self-contained breathing systems.
- Communication systems.
- Recognition of symptoms due to working in extreme temperatures.

At least 50% of this training must be practical, with simulations of emergencies and rescues.

For persons performing air quality checks, in addition to general training:

- Basic training in occupational health and safety.
- Specific training in using the air-quality measurement equipment used in such measurements.

For repair personnel, in addition to general training:

- Specific training in handling chemical products.
- Personal protective equipment for chemicals.

For working at height and/or on ropes, in addition to general training:

- Working at height and/or on ropes.
- Rescues at height.
- Category 3 personal protective equipment: systems to prevent falling from height.

At least 50% of this training must be practical, with simulations of emergencies and rescues.

Specific training for the supervisory team, in addition to general training:

- Specific training for rescuing injured persons from confined spaces.
- Additional first aid training.
- Training in managing emergencies.

At least 50% of this training must be practical, with simulations of emergencies and rescues.

8. Physical load requirements

As we saw in the *Environmental requirements* section, it is very important to understand the physical workload involved, as this enables us to establish whether the work can be performed in the blade in extreme conditions or not.

There are a number of methods for calculating the physical workloads to be carried out; however, we should dismiss those that establish physical workloads by type of employment category, as they are not precise enough. We should aim to choose those that establish the physical load by task or operation, as these are always much more precise.

As we see in many of the calculation tables for these methods, the values are in w/m^2, leading to the question: what is the surface area of the human body? We can calculate this in a basic way from the following formula:

$$x = \sqrt{\frac{\text{weight x height}}{3600}}$$

Where x is in square metres, weight in kilograms and height in centimetres.

Finally, if available, we can take direct measurements of the physical load during the work. This is the most reliable method, clearly establishing the physical workload.

Given the nature of the work area –inside the blade- we recommend heart rate monitoring, as this does not get in the way very much and allows work to be performed normally.

We recommend reading *Méthodologie générale d'interpretation des enregistrements continus de fréquence cardiaque aux postes de travail.* (ref.4), as this establishes criteria for assessing the energy consumed in the task based on the worker's heart rate, and how well the worker is adapting to the workplace. If a worker does not have the physical capacity for such work, they should be replaced by someone else who does.

9. Personal protective equipment

When entering the blade, the worker must always wear:

- A rescue harness.
- A helmet.
- Full clothing or overalls.
- Anti-dust goggles.
- Gloves to protect against mechanical injury.
- Oxygen measurement equipment.
- Safety boots with non-slip protection (not personal protective equipment).

If the work is going to last a long time a breathing system should be incluyed.

It may be:

- Self-contained breathing apparatus.

- Semi-self-contained breathing apparatus.
- A negative pressure air extraction system to ensure a 20.5% O_2 oxygen concentration.
- It is preferable to avoid self-contained and semi-self-contained breathing apparatus, as this makes it difficult to access the interior of the blade, increasing stress on the user.
- Breathing protection: During repair work, if self-contained breathing apparatus is not being used, A2P3 protection filters must be used based on a hygienic assessment of the work. In this case, oxygen detectors must be used systematically.

If the blade being worked on is installed, the following is required:

- Equipment for working at height or working on ropes (anti-fall systems, safety ropes, etc).
- Other personal protective equipment must be suitable for this situation (safety harness for working in positions or anti-fall safety system instead of the rescue harness, helmet for working at height rather than the work helmet, etc.).

If the work takes place under extreme environmental conditions:

- Protective clothing for heat or cold.

10. Authorised work equipment

Workers must be equipped with portable lighting equipment when entering the blade, even when an internal lighting system has been installed in the blade because of the extent of the work.

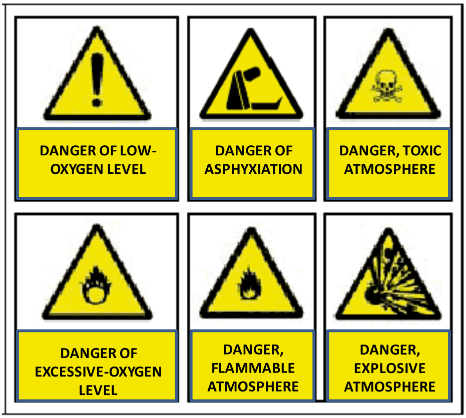
Wherever possible, all equipment taken into the blade for measurement, checks or repairs must comply with ATEX regulations.

11. Signage

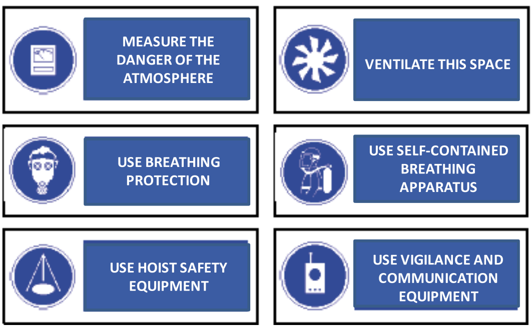
As the interior of the blade has been defined as a confined space, the access must be indicated using specific signage and access should be restricted. It is strongly recommended (ref. 5) that access to the interior of the blade should require a key in order to ensure security.

Although some such signs are widely used, there are no regulations in place for these; therefore, for information and to promote their use, we will refer to some of the most common, classified by their type:

This can be complemented by appropriate signs for the risk considered:

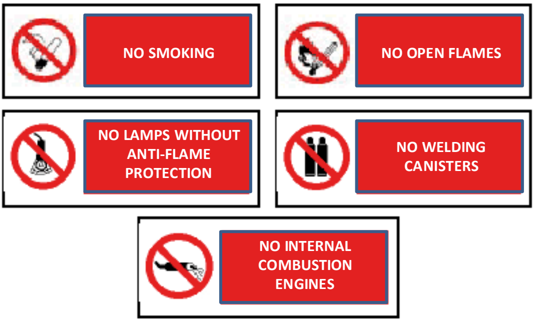


Signs indicating control measures:



Signs indicating basic occupational health and safety measures:

Prohibitions signs for confined spaces:



12. Organisation and supervision

12.1 Work permits

A work permit ensures that a formal control system has been established to guarantee that all occupational health and safety measures have been followed before workers enter confined spaces to carry out work. This is also a form of communication between the site management, supervisors and the staff responsible for dangerous work. The essential aspects of the work permit are:

- Clear identification of who can authorise certain workers to perform the tasks (and the limits on their authority).
- Clear identification of who is responsible for specifying the preventative measures required (for example, isolation, air quality measurement, security and emergency measures, etc.).

- They establish the provisions that contractors have been informed of and have taken into account.
- They establish the training and skills needed for particular tasks.
- They establish control and audit points to ensure that the system is functioning as planned.

We recommend the use of work permit models that deal with all the aspects detailed in the Inspection Activities in Confined Spaces Guide and Protocol (ref. 5).

12.2 External vigilance

During all stages of the work, from preparation through to performance, and whilst there are workers inside the blade, there must always be at least one support person either on the outside or in the gondola. This person must be duly qualified in occupational health and safety, being the person stipulated in the work permit as such.

IMPORTANT: This person MUST not be in the manhole or its surrounding area, to avoid them being affected by any fires or explosions inside the blade.

This person must have the following

- The communication resources needed to be in permanent vocal contact with the workers performing the work.
- The communication resources needed to establish contact with such external rescue resources as are needed.
- The equipment needed for rescue of the worker.
- Additional first-aid training.
- Emergency management training.

12.3 Checks prior to entry and during performance of the work

In the event that semi-self-contained or self-contained breathing apparatus is not used, or air condition measurements must be taken inside the blade.

- The person responsible for carrying out these checks will have at least basic occupational health and safety qualifications.

- It is useful to have a study of the pollutants inside the blade.
- The workers should have portable flammable gas measurement equipment (depending on the pollutant study for the inside of the blade and the oxygen level).

Initial and periodic measurements must be taken of the thermo-hygrometric conditions inside the blade to establish the WGBT index for the work.

For operations involving installed blades, wind speeds must be monitored as this limits rescue capacity using cranes. By way of reference: many cranes have wind limiters set at 12 m/s.

13. Emergencies

Prior to the start of work, all procedures for emergencies within the shaft must be prepared.

The workers involved in the tasks must be aware of these procedures.

These procedures must address the following, at least:

- Accidents:
  - Fire or explosion inside the blade.
    - Need for fire extinguishing equipment.
  - Injuries to the worker and broken bones.
  - The worker losing consciousness inside the blade.
- How the worker will be removed from the blade and to ground level when suffering a range of conditions:
  - Rescue equipment needed.
  - First aid equipment needed.
  - Information for the control centre on the specific tasks being carried out.

The workers involved in such activities must be trained in emergencies. This must include practical training and simulations in conditions as similar as possible to reality.

ANNEX 1. Selecting staff to work in hot environments

We recommend that policies for working in hot environments should be based on the document "Heat stress control and heat casualty management. TBMED AFPAM 48-152 (I). United States Army" (ref.3), as this is exhaustive in coverage and the work clothing of a worker inside a blade is very similar to that described.

In summary, we can establish:

- In our case, work clothing should consist of:
    - Overalls.
    - Safety boots.
    - Anti-fall harness.
    - Helmet.
    - Gloves.

This clothing should be similar to that described in the above document :

- Conditions in the blade should be measured to calculate the WBGT index.
- The physical load of the work to be carried out should be calculated.
- The resulting temperature of the human body at this work rate should be calculated. We strongly recommend that the work should be kept within the CHS (Compensated Heat Stress) zone, avoiding entering the UCHS (Uncompensated Heat Stress) zone.

Source: GAMESA

Source: GAMESA

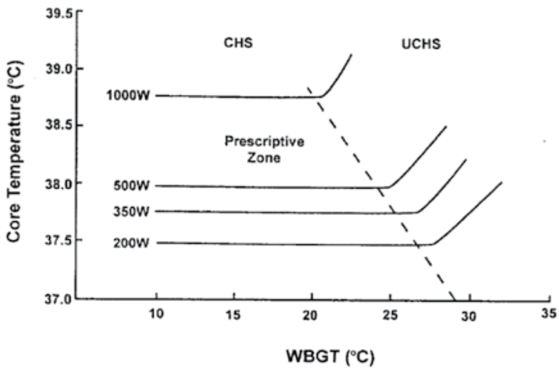


Figure 1. Illustration of core temperature (steady-state) responses during physical work (four metabolic rates) during Compensated (CHS) and Uncompensated (UCHS) heat stress. (ref.3)

- Once these two variables have been established, the quantity of liquids to be consumed and the work/break times can be calculated. The limits established in table are to be respected.

Table 2. Fluid replacement and work/rest guidelines for warm weather training conditions (Applies to average size and heat-acclimatized soldier wearing battle dress uniform (BDU), hot weather.)

		Easy Work (250 W)		Moderate Work (425 W)		Hard Work (600 W)	
Heat Category	WBGT[6,7] Index (° F)	Work/Rest[1,3]	Water[4,5] Intake (qt/hr)	Work/Rest	Water Intake (qt/hr)	Work/Rest	Water Intake (qt/hr)
1	78 – 81.9	No Limit (NL)[2]	½	NL	¾	40/20 min	¾
2 (green)	82 – 84.9	NL	½	50/10 min	¾	30/30 min	1
3 (yellow)	85 – 87.9	NL	¾	40/20 min	¾	30/30 min	1
4 (red)	88 – 89.9	NL	¾	30/30 min	¾	20/40 min	1
5 (black)	>90	50/10 min	1	20/40 min	1	10/50 min	1

Easy Work	Moderate Work	Hard Work
• Weapon maintenance • Walking hard surface at 2.5 mph, <30 pound (lb) load • Manual of arms • Marksmanship training • Drill and ceremony	• Walking loose sand at 2.5 mph, no load • Walking hard surface at 3.5 mph, <40 lb load • Calisthenics • Patrolling • Individual movement techniques, that is low crawl, high crawl • Defensive position construction	• Walking hard surface at 3.5 mph, ≥40 lb load • Walking loose sand at 2.5 mph with load • Field Assaults

Notes:
1. The work/rest times and fluid replacement volumes will sustain performance and hydration for at least 4 hours of work in the specified heat category. Fluid needs can vary based on individual differences (± ¼ qt/hr) and exposure to full sun or full shade (± ¼ qt/hr).
2. NL equals no limit to work time per hour (up to 4 continuous hours).
3. Rest means minimal physical activity (sitting or standing), accomplished in shade if possible.
4. CAUTION: Hourly fluid intake should not exceed 1 ½ quart.
5. Daily fluid intake should not exceed 12 quarts.
6. If wearing body armor, add 5° F to WBGT index in humid climates.
7. If wearing NBC clothing (mission-oriented protective posture (MOPP 4)), add 10° F to WBGT index for easy work, and 20° F to WBGT index for moderate and hard work.

•The probability of exhaustion of someone subject to this workload is:

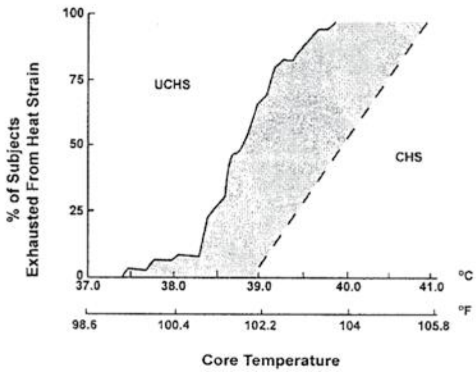


Figure 2. Relationship between core temperature and incidence of exhaustion from heat strain during physical work in UCHS and CHS. (ref.3)

The document also sets out policies for acclimatising the workers.

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